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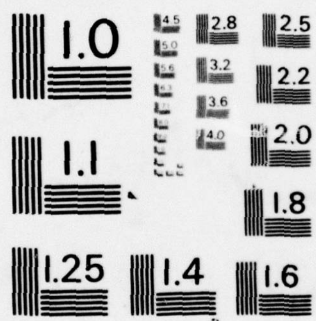

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ABSTRACT

This Interim Technical Report summarizes the research carried out under Grant AFOSR 76-2937 during the period 1 September 1975 - 31 August 1976. The research activities were concerned with three distinct problem areas: (1) the development of efficient algorithms and heuristic techniques for the reconstruction of three-dimensional scenes from multiple photographs, (2) the study of improved coding schemes for line-drawing data, especially topographic maps, and (3) the development of thoroughly tested computer programs for eliminating the "hidden" lines in perspective views of complex planar-faced and quadric-surface-face objects. The individual research areas are briefly described and abstracts of the publications issued during the reporting period are given.

TABLE OF CONTENTS

AUTOMATIC DATA PROCESSING TECHNIQUES FOR GRAPHIC-DATA DISPLAY, GENERATION AND ANALYSIS

SUMMARY OF RESEARCH

1. General

The research objectives of this project are to develop improved computer techniques for the processing of graphical data. During the past year three particular investigations were pursued. The first of these was concerned with the reconstruction of three-dimensional scenes from multiple photographs, the so-called scene analysis of "image-understanding" problem. The second was devoted to the development of improved computer representations of line-drawing data (e.g., topographic maps), with special emphasis on data compactness and precision. The third investigation had as its goal the development of a thoroughly tested computer program for the removal of the "hidden" lines in the perspective projections of both planar-faced and quadric-surface-faced objects. The work is briefly summarized here. For detailed descriptions of the research the reader is referred to the publications issued during the period, abstracts of which are included in this report.

2. Reconstruction of Three-Dimensional Scenes

A problem of wide current interest in computer image processing is that of scene analysis or "image understanding". It is a form of automatic photo-interpretation of a particularly sophisticated kind. The objectives for it fall generally into two categories: the "recognition" (i.e., classification) of three-dimensional objects from among a set of known objects, and the "description" of unknown objects according to specified features. Thus in the first, a trailer truck in a scene might be identified by creating a computer model of it and then comparing this model against a set of stored models of different kinds of trucks and other vehicles. In the second, a computer model is also created; however, no models for comparison are presupposed to exist. Instead the model is categorized according to selected features of interest - such as, does it have axes of symmetry, does it have any pairs of parallel sides, is it mainly convex, what major concavities does it have, where is its center of gravity (centroid), is it bounded by regular planar or curved surfaces (as most man-made objects are), and is it multiply-connected?

The approach pursued here has been based on the use of multiple photographs taken from different vantage points or under different lighting conditions. The use of multiple wide-angle stereo photographs has the advantage of yielding superior distance information about the scene and permitting better angular coverage; however, in contrast to conventional narrow-angle stereo, matching of corresponding edges and vertices in pairs of photographs is a major task, requiring extensive computer processing [8, 9]*.

The effort has proceeded along two complementary paths. In the first, photographs of the scenes are individually processed to extract "clean" outlines of the objects. In the second, the outlines obtained from photographs taken from different vantage points are processed to correlate edges (straight or curved) and vertices, and finally to assemble a 3D computer model.

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* The numbers in brackets refer to items in the list of references at the end of this report.

Considerable progress has been achieved in the work to date, especially with respect to constructing models of planar-faced objects [9], or correlating vertices appearing in different projections [8, 10, 5], fitting second-degree equations to the projections of curved-surface intersections [11], and of extracting outline information (edges) from noisy photographs of both planar-faced and curved-surface bodies [1, 12, 13]. Throughout the work, the bodies are assumed to be unknown to the procedure. However, it is assumed that the bodies are bounded by faces which are either quadric or planar, and that all their vertices are formed by exactly three faces.

The photographs are taken from different vantage points, with only the restriction of "generality", i.e., that a slight shift in the vantage point will not alter the topology of the projection. The photographs are assumed to be sufficiently "noisy" so that the preprocessor extracting the edges will present imperfect data to the program, with some junctions erroneously reported and with some lines missing.

A technique for validating the extracted junctions and for matching features in the different projections has been tested and evaluated. The technique utilizes some new grammar rules discovered during the past year to apply to pictures of curved and planar-faced solid bodies.

The model-building program handles all pictures simultaneously, and the parsing of every picture is supported dynamically by the results gotten up to this point from the other pictures. Through the parsing of the pictures many preprocessor errors are detected and corrected. Utilizing picture comparison together with the grammatic rules aids the program in determining where to look again for features which may have been missed during the initial processing stage. The work has been the subject of a doctoral dissertation which was completed during the past year [7].

3. <u>Computer Representations of Line Drawing Data</u>

A problem that continues to demand attention is that of efficient encoding of cartographic data. The problem has in recent years gained especial importance from the massive efforts being made in the U. S. and in various NATO countries to computerize all map data, and by the large amounts of new map data being generated from satellites such as ERTS and LANDSAT. One encoding technique, developed by the principal investigator under AFOSR sponsorship s[illegible] years ago is the so-called chain code which is characterized by a combination of efficient storage, simplicity of processing, ease of encoding, and convenience for display. The code, which uses octal digits to represent the eight possible incremental directions on a square grid, has found wide acceptance [14]. More efficient "dialects" of the chain code are possible, but the increased compactness is invariably achieved at the cost of more complex encoding and more time-consuming computer processing.

During the past year it was discovered that improved codes are possible which will be both more compact <u>and</u> involve shorter processing time [4]. These codes extend the 8-point chain concept to 16-point, 24-point, 32-point, and even 48-point configurations. Thus for the 24-point code, the next nodes on the square coding grid are not only the immediately neighboring nodes but also those one additional grid spacing (straight or diagonal) away. Taking into account the fact that the next node in sequence when encoding a contour can be probabilistically predicted, a 3-bit code word is normally sufficient, with progressively longer code words for less frequently occurring node sequences. Since the number of code words will be almost one half of that for the conventional 8-point chain code (for which the corresponding minimum code word is of length 2), a saving of approximately 33 per cent is realized. In addition, since the angular resolution is finer for the 24-point code than for the 8-point code, a slightly coarser encoding grid can be used, resulting in a further gain of efficiency. Still better performance would be realizable with the 32-point code. For codes beyond 48-point, the increased processing complexity as well as the decreasing correlation in the curve node sequences with increasing distance will then cause the efficiency to diminish again (the exact stage at which this occurs has not been determined as yet). Coding configurations for chain codes from 4-point to 48-point are shown in Fig. 1. A contour encoded according to the 4-, 8-, 16-, 24- and 32-point chain codes is illustrated in Fig's. 2 and 3.

4. Hidden-Line Elimination in Projections of Solids

During the past year an effort was made at the request of personnel from the Air Force Flight Dynamics Laboratory, Wright-Patterson AFB, to develop a fully-tested operational program for the elimination of the "hidden" lines in the projections of planar-faced and quadric-surface bounded solids. Algorithms for this had been previously developed by the principal investigator and his associates; however, no reliable implementations were available. During the course of the year two versions of a new hidden-line removal program were written and thoroughly debugged, an interactive version for use on an ADAGE AGT-30 graphics system and a batch version for use on a CDC 6600 computer. Copies of these programs, with necessary documentation, can be made available to anyone interested.

In addition, a hidden-line removal program for quadric-surfaced bodies was implemented on an IBM 360/67 during the past year. This latter program is, however, still somewhat difficult to use and some further work is required before it can be made available for general use.

An example of hidden-line elimination for some simple planar-faced objects, generated with the interactive version of the program, is shown in Fig. 4. Observe that one of the objects is a multiply-connected polyhedron and one is not a polyhedron at all. Some pictures of curved-surface objects with the hidden lines removed, generated by the curved-surface handling program, are shown in Fig's. 5, 6, and 7.

Through the work with the hidden-line elimination programs some interesting new results were obtained which relate to schemes for efficiently representing curved-surface bodies in a computer. The results were published in a report [3] and a technical paper [6] during the past year.

PUBLICATIONS

1. A. Martelli, "An Application of Heuristic Search Methods to Edge and Contour Detection," Communications of the ACM, vol. 19, (2), February 1976, pp. 73-83.

Abstract: This paper presents a method for detecting edges and contours in noisy pictures. The properties of an edge are embedded in a figure of merit and the edge detection problem becomes the problem of minimizing the given figure of merit. This problem can be represented as a shortest path problem on a graph and can be solved using well-known graph search algorithms. The relations between this representation of the minimization problem and a dynamic programming approach are discussed, showing that the graph search method can lead to substantial improvements in computing time. Moreover, if heuristic search methods are used, the computing time will depend on the amount of noise in the picture. Some experimental results are given; these show how various information about the shape of the contour of an object can be embedded in the figure of merit, thus allowing the extraction of contours from noisy pictures and the separation of touching objects.

Key Words and Phrases: picture processing, pattern recognition, edge detection, contour detection, contour following, optimization problems, dynamic programming, shortest path, heuristic search methods, problem solving methods.

2. M. Adamowicz and A. Albano, "A Solution to the Rectangular Cutting-Stock Problem," IEEE Trans. on Systems, Man and Cybernetics, vol. SMC-6, (4), April 1976, pp. 302-310.

Abstract: A method of solving a version of the two-dimensional cutting-stock problem is presented. In this version of the problem one is given a number of rectangular sheets and an order for a specified number of each of certain types of rectangular shapes. The goal is to cut the shapes out of the sheets in such a way as to minimize the waste. However, in many practical applications computation time is also an important economic consideration. For such applications the goal may be to obtain the best solution possible without using excessive amounts of computation time. The method of solution described here avoids exhaustive search procedures by employing an approach utilizing a constrained dynamic programming algorithm to lay out groups of rectangles called strips. This paper also describes the results obtained when the algorithm was tested with some typical rectangular layout problems.

3. J. Levin, "A Parametric Algorithm for Drawing Pictures of Solid Objects Bounded by Quadric Surfaces," Tech. Rept. CRL-46, March 1976, 67 p.

Abstract: An algorithm is described for generating two-dimensional, visible-line projections of three-dimensional objects that are bounded by patches of quadric surfaces.

The main task of the algorithm is the calculation of intersections between quadric surfaces. A parameterization scheme is used. Each quadric-surface intersection curve (QSIC) is represented as a set of coefficients and parameter limits. Each value of the parameter represents at most two points, and these may easily be distinguished. This scheme can find the coordinates of points of even quartic (fourth-order) intersection curves, using equations of no more than second order.

Methods of parameterization of each type of QSIC are discussed, as well as the problems of surface bounding and hidden-surface removal.

4. H. Freeman, "Analysis of Line Drawings," Proceedings of NATO Advanced Study Institute on Image Processing, Bonas, France, June 1976, 24 p. (Proceedings available through IRIA, Rocquencourt, France)

Abstract: This paper is concerned with the computer analysis of line drawings. Line drawings serve as a medium for communication in a large variety of fields, and the processing to which they may be subjected is very much dependent on the application of interest. The paper discusses different types and features of line drawings, and reviews the more important schemes for quantizing and encoding them. Algorithms for analyzing line drawings are described, with particular emphasis on extracting geometric and shape-related features.

5. R. Shapira and H. Freeman, "A Cyclic-Order Property of Bodies with Three-Face Vertices," accepted for publication in IEEE Trans. on Computers.

Abstract: A cyclic-order property is defined for three-dimensional bodies with vertices formed by three faces. The property is useful in resolving ambiguities caused by the extraction of imperfect line data from photographs of such bodies. The property augments the grammatical rules that govern the possibility or impossibility of the existence of three-dimensional bodies corresponding to particular two-dimensional line-structure projections.

6. J. Levin, "A Parametric Algorithm for Drawing Pictures of Solid Objects Bounded by Quadric Surfaces," presented at Third Annual Conference on Computer Graphics, Interactive Techniques and Image Processing - SIGGRAPH 76; to appear also in special issue on computer graphics, Communications of the ACM, vol. 19, (10), October 1976.

Abstract: An algorithm for drawing pictures of three-dimensional objects, with surfaces made up of patches of quadric surfaces, is described.

The emphasis of this algorithm is on calculating the intersections of quadric surfaces. A parameterization scheme is used. Each quadric surface intersection curve (QSIC) is represented as a set of coefficients and parameter limits. Each value of the parameter represents at most two points, and these may easily be distinguished. This scheme can find the coordinates of points of even quartic (fourth-order) intersection curves, using equations of no more than second order.

Methods of parameterization for each type of QSIC are discussed, as well as surface bounding and hidden-surface removal.

7. R. Shapira, "Computer Reconstruction of Bodies Bounded by Quadric Surfaces from a Set of Imperfect Projections," Tech. Rept. CRL-48, September 1976, 116 p.

Abstract: This thesis describes a computer program for constructing a description of solid bodies from a set of n pictures of the bodies. The bodies are assumed to be bounded by faces which are quadric or planar, and they are restricted to have all their vertices formed by exactly three faces. The pictures are taken from different vantage points, with the restriction that a slight shift in vantage point will not alter the topology of the picture. It is assumed that the program receives outline information from a preprocessor which has extracted this information from the pictures. The outline information (set of line structures) may be imperfect in that some junctions may be erroneously reported and some lines may be missing. However, all lines due to shadows are assumed to have been eliminated by the preprocessor.

The thesis includes a technique for establishing the validity of the junctions presented by a preprocessor as well as for matching corresponding features in line structures derived from the different pictures. New grammar rules for line-drawing projections of curved and planar solid bodies are developed. These are useful in parsing the line drawings. They have also led to the definition of a new family of impossible objects. The program works simultaneously with all the available line structures. The parsing of every line structure is supported dynamically by the results gotten thus far from the parsing of the other line structures. Through the parsing of the line structures the use of picture comparison and the application of the grammar rules, many of the preprocessor errors are detected and partly corrected. The program also can provide feedback to the preprocessor in the form of suggestion as to where to look again for lines in the pictures.

The program utilizes the extracted line structures corresponding to the different bodies in all the pictures to determine the set of faces (insofar as possible) for every body. Every face is defined by an ordered set of n-tuples. The n-tuples are the matched lines and junctions in the n different pictures. The three-dimensional coordinates of the vertices and the equations of the faces can then be determined from these n-tuples. The program was written in PL/I and has been tested on several scenes.

PRESENTATIONS

Invited presentations by Principal Investigator:

1. "Image Processing and Scene Analysis", IEEE Workshop on Data Structures and Pattern Recognition, Albuquerque, New Mexico, 11-13 February 1976.

2. "Computer Scene Analysis", IEEE Section Meeting, Norwalk, Conn., 8 April 1976.

3. "Relationship Between Graphics and Image Processing", SIGGRAPH 76, Philadelphia, Penna., 14 July 1976.

4. "Comparative Analysis of Line Pattern Coding Schemes", Conference on Formal Psychophysical Approaches to Visual Perception, Nijmegen, The Netherlands, 26-28 July 1976.

5. "Analysis of Shape", Engineering Foundation Conference on Algorithms for Image Processing, Rindge, New Hampshire, 9-13 August 1976.

REFERENCES

Note: Abstracts for items 1 through 7, which were published during the past year, are included in the section on PUBLICATIONS.

1. A. Martelli, "An Application of Heuristic Search Methods to Edge and Contour Detection," Comm. ACM, 19, (2), February 1976, 73-83.

2. M. Adamowicz and A. Albano, "A Solution to the Rectangular Cutting-Stock Problem", IEEE Trans. on Systems, Man and Cybernetics, Vol. SMC-6, (4) April 1967.

3. J. Z. Levin, "A Parametric Algorithm for Drawing Pictures of Solid Objects Bounded by Quadric Surfaces", Tech. Rept. CRL-46, Computer Research Laboratory, Electrical and Systems Engineering Dept., Rensselaer Polytechnic Institute, Troy, NY 12181, March 1976.

4. H. Freeman, "Analysis of Line Drawings", Proc. NATO Advanced Study Institute on Digital Image Processing, 14-25 June 1976, Bonas, France (to be published in book form, preprints avilable). (Proceedings available through IRIA, Rocquencourt, France).

5. R. Shapira and H. Freeman, "A Cyclic-Order Property of Bodies with Three-Face Vertices", Tech. Rept. CRL-42, Div. Appl. Sci., New York University, August 1975.

6. J. Z. Levin, "A Parametric Algorithm for Drawing Pictures of Solid Objects Bounded by Quadric Surfaces", presented at Third Annual Conference on Computer Graphics, Interactive Techniques, and Image Processing, Philadelphia, 14-16 July 1976. To appear also in special issue on computer graphics, Communications of the ACM, Vol. 19, (10), October 1976.

7. R. Shapira, "Computer Reconstruction of Bodies Bounded by Quadric Surfaces from a Set of Imperfect Projections", Tech. Rept. CRL-48, Rensselaer Polytechnic Institute, September 1976.

8. R. Shapira, "A Technique for the Reconstruction of a Straight-edge, Wire-frame Object from Two or More Central Projections", Comp. Graphics and Image Proc., 3, (4), Dec. 1974, 318-326 (see also AD 751 282).

9. A. Rabinowitz, "Reconstruction of Polyhedra from Sets of Their Perspective Projections", Tech. Report 403-20, doctoral dissertation, Dept. of Electrical Engineering, New York University, Bronx, N.Y. (April 1971). (AD 732 300).

10. R. Shapira, "Computer Reconstruction of Quadric-Surfaced Objects from Two or More Visible-Line Projections", Tech. Rept. CRL-44, Div. Appl. Sci., New York University, August 1975. (AD-A020 628)

11. A. Albano, "Representation of Digitized Contours in Terms of Conic Arcs and Straight-Line Segments", Comp. Graphics and Image Proc., 3, 1974. 318-326.

12. E. U. Ramer, "The Transformation of Photographic Images into Stroke Arrays", IEEE Transactions on Circuits and Systems, Vol. CAS-22, No. 4, April 1975, pp. 363-374.

13. E. U. Ramer, "Extraction of Line Structures from Photographs of Curved Objects", Comp. Graphics and Image Proc., 4, 1975, 81-103.

14. H. Freeman, "Computer Processing of Line-drawing Images", Computing Surveys, 6, (1), March 1974, 57-97. (AD 777 929).

LIST OF ILLUSTRATIONS

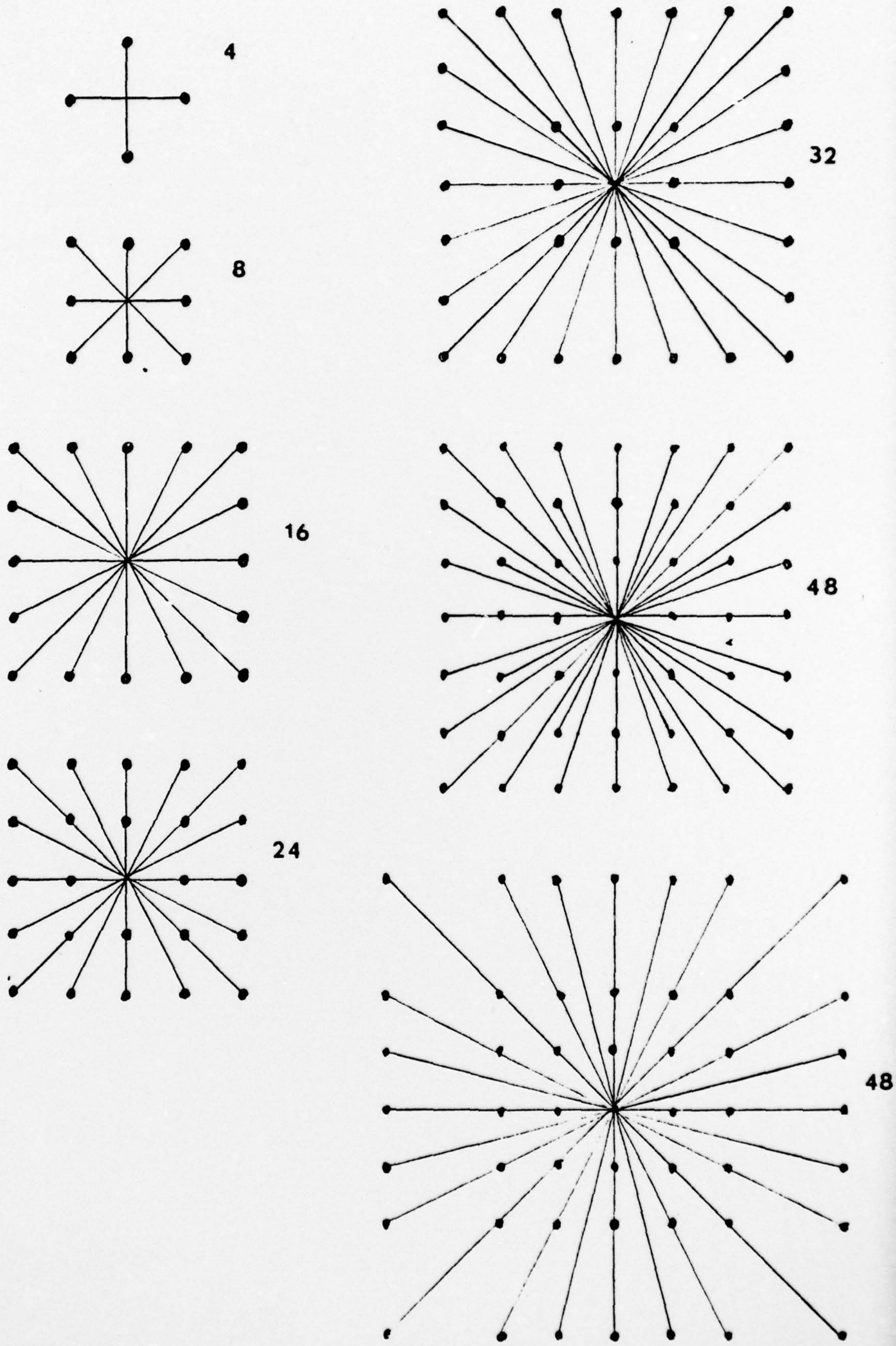


Fig. 1. Coding Configurations for 4-Point, 8-Point, 16-Point, 24-Point, 32-Point, and 48-Point Chain Codes

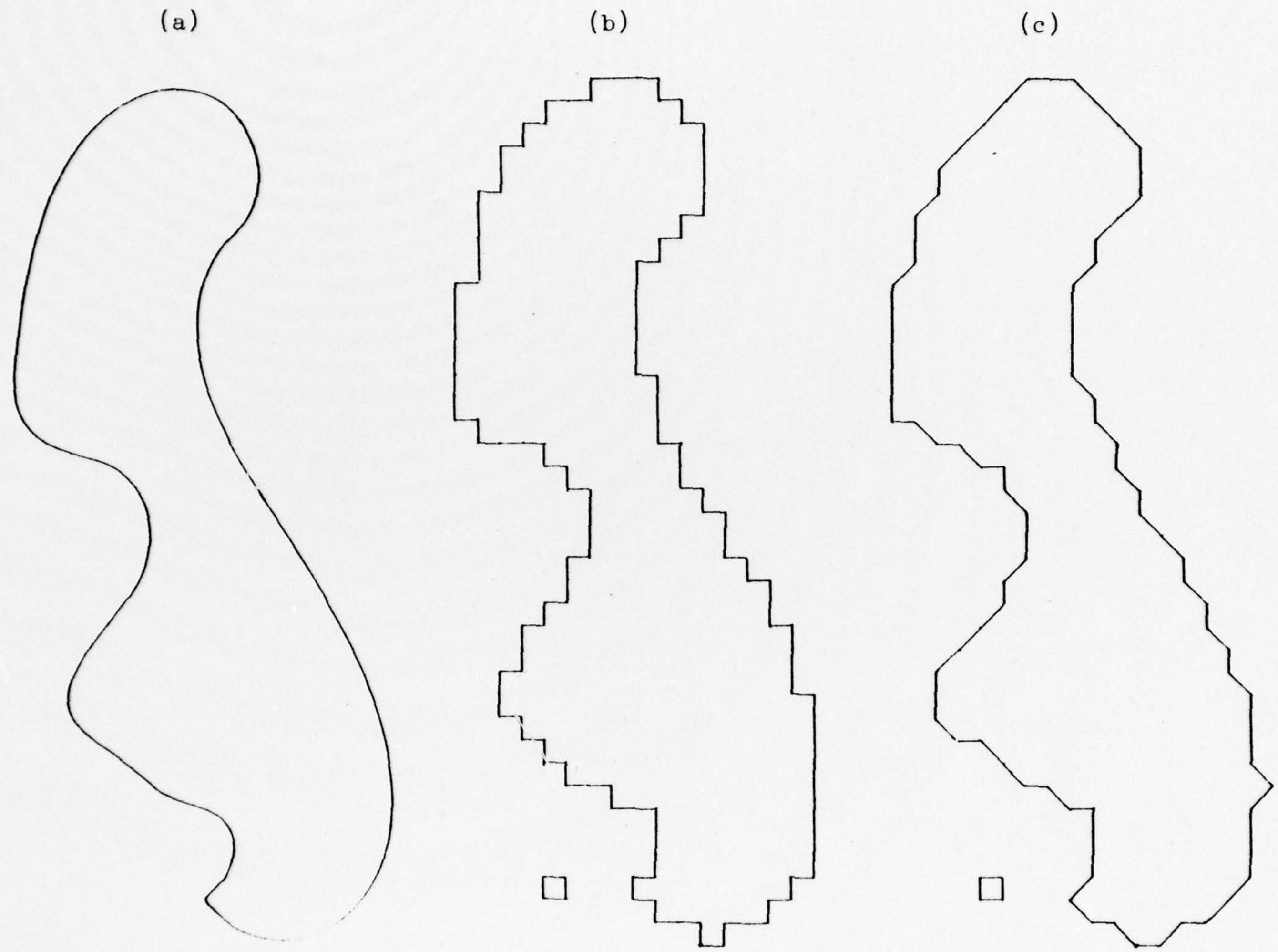


Fig. 2. Contour (a) Encoded According to 4-Point (b) and 8-Point (c) Chain Codes

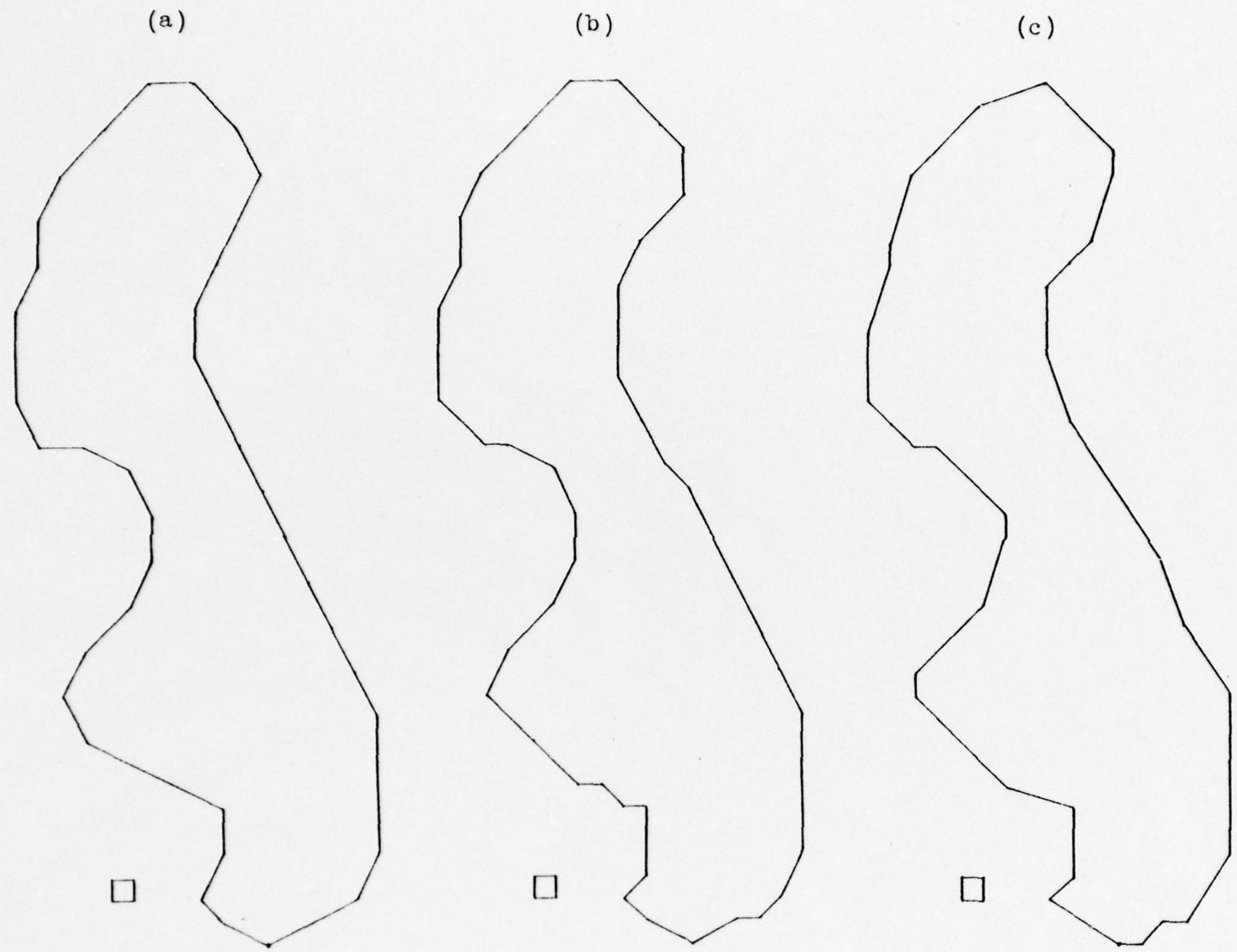


Fig. 3. Contour of Fig. 2(a) Encoded According to (a) 16-Point, (b) 24-Point, and (c) 32-Point Chain Codes.

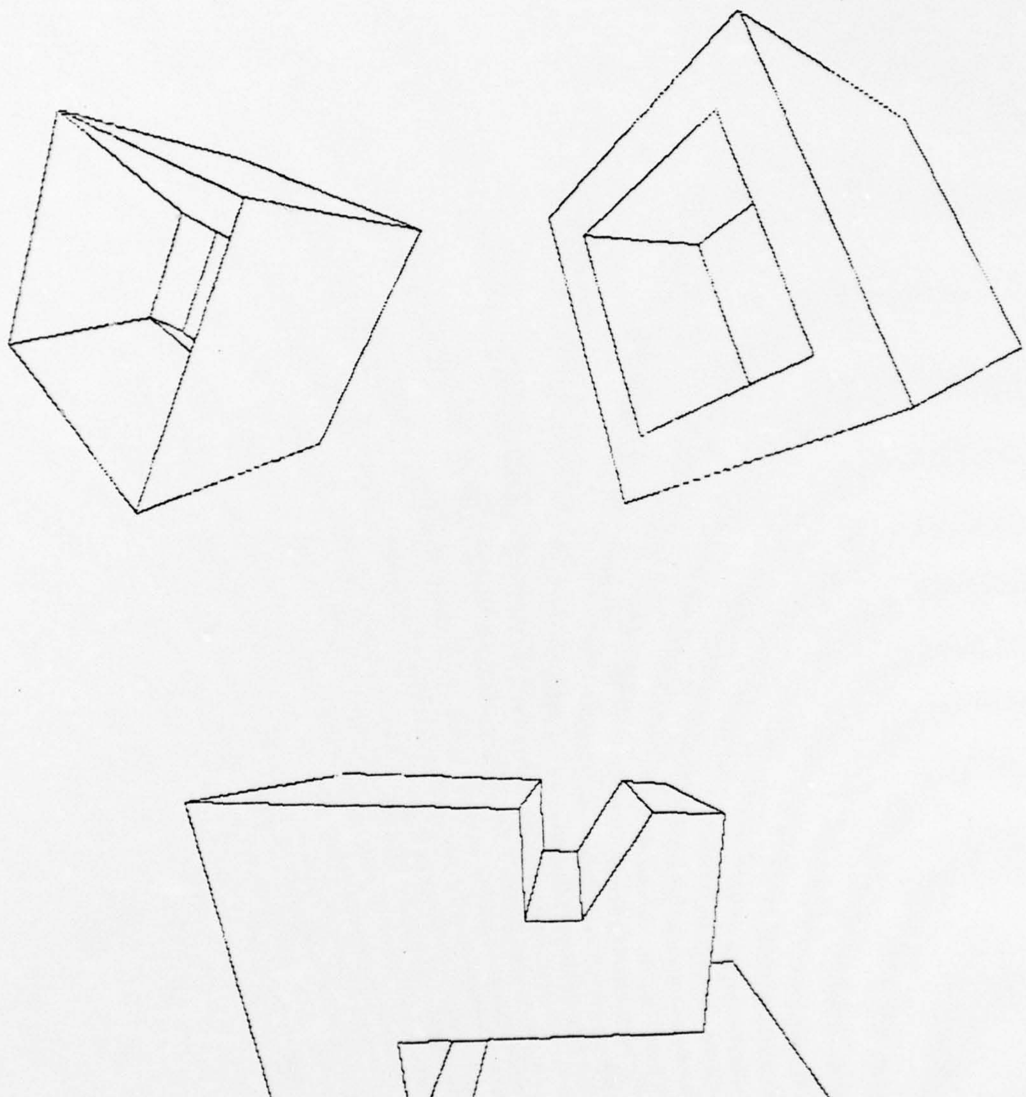
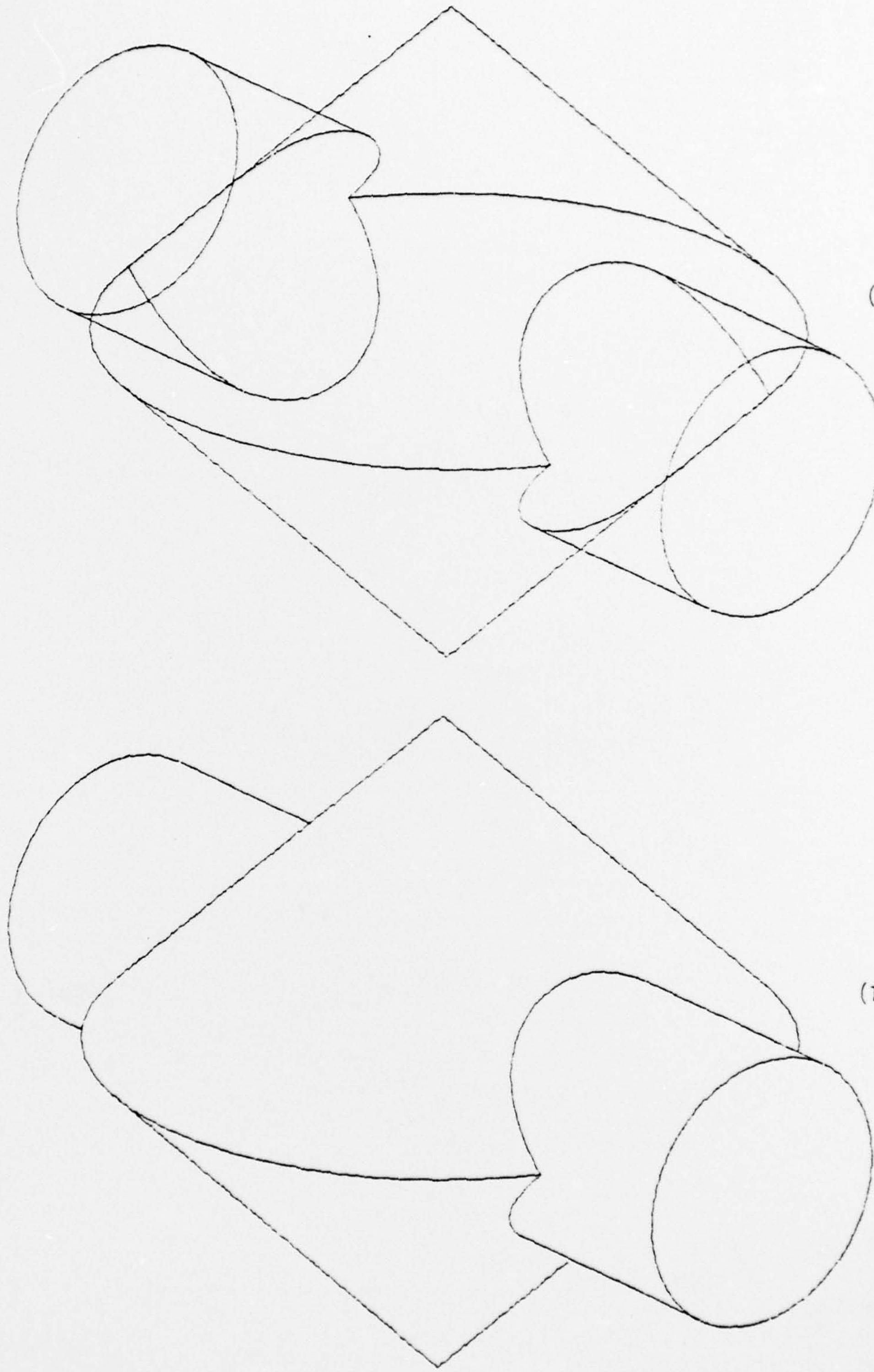


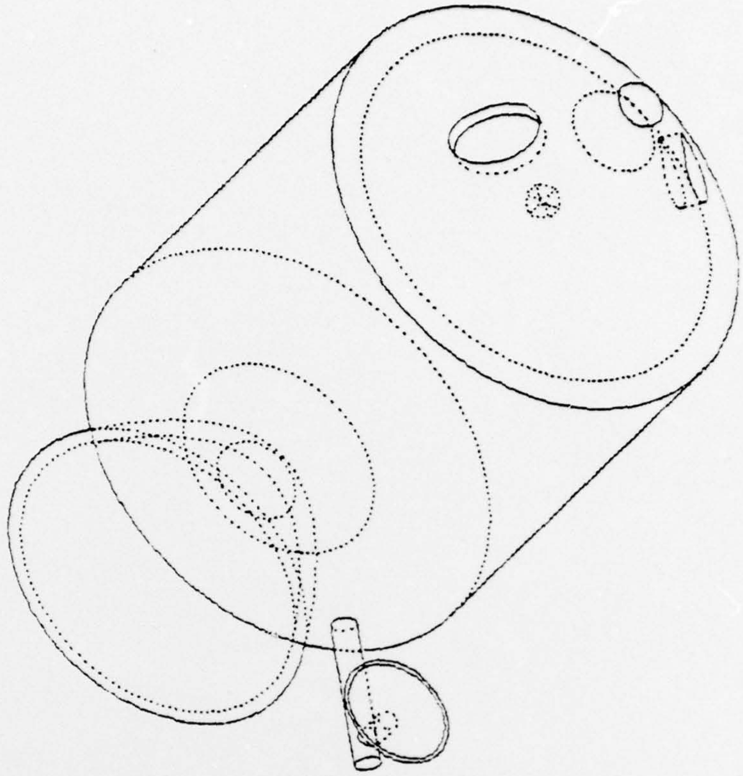
Fig. 4. Three Planar-Faced Objects with Hidden Lines Deleted



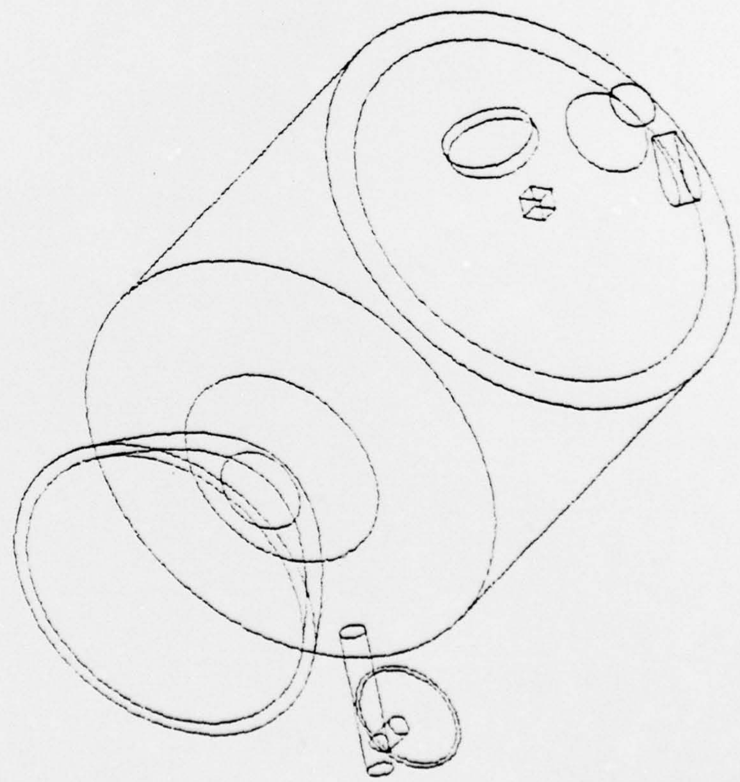
(a)

(b)

Fig. 5. A Pair of Cones Cut by a Cylinder. (a) All Lines Shown. (b) Hidden Lines Removed.



(b)



(a)

Fig. 6. Space Ship. (a) All Lines Shown.
(b) Hidden Lines Dashed.

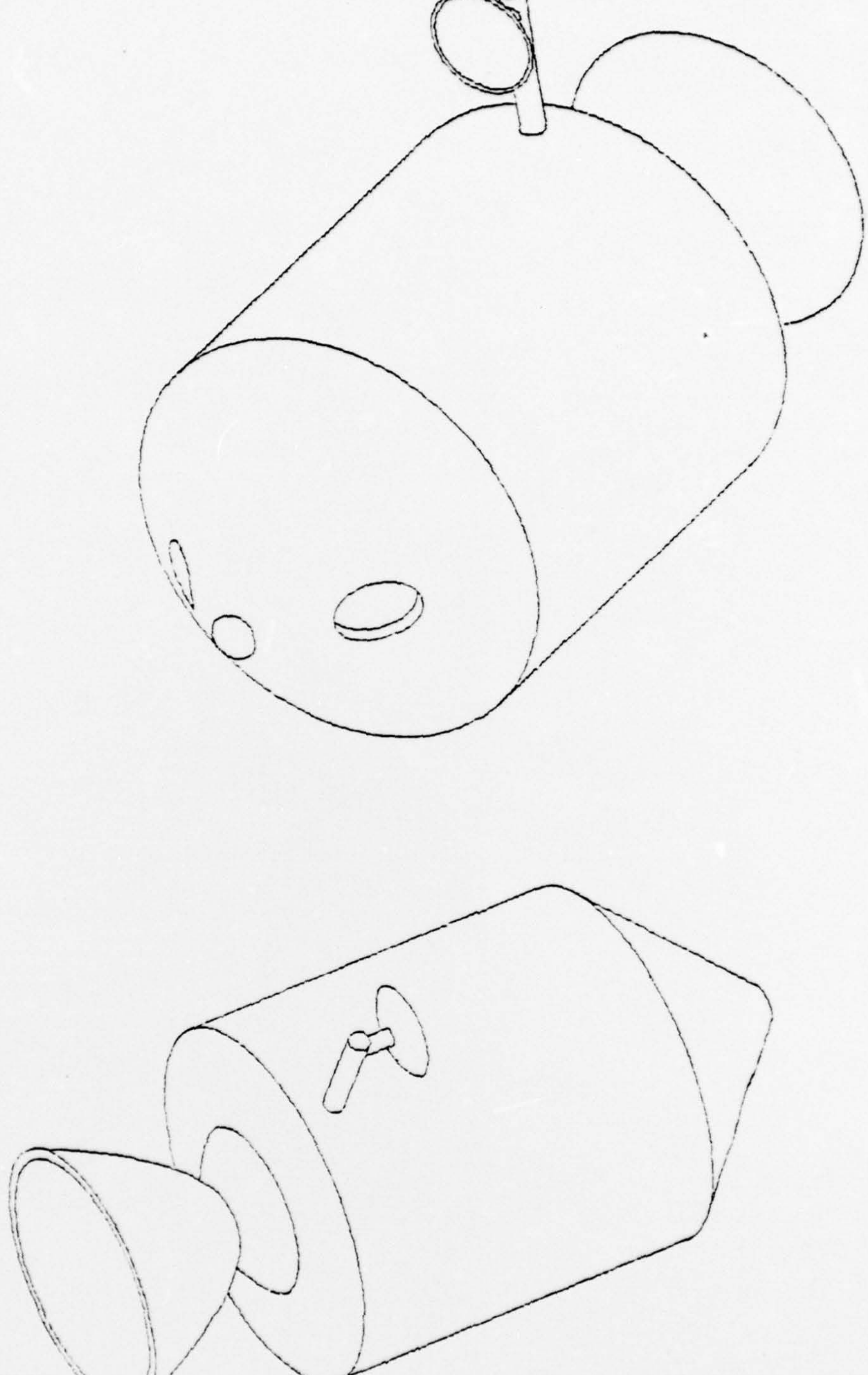


Fig. 7. Two Views of Space Ship with Hidden Lines Removed

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photo interpretation
Line-Drawing coding
Hidden-line removal

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This Interim Technical Report summarizes the research carried out under Grant AFOSR 76-2937 during the period 1 September 1975 - 31 August 1976. The research activities were concerned with three distinct problem areas: (1) the development of efficient algorithms and heuristic techniques for the reconstruction of three-dimensional scenes from multiple photographs, (2) the study of improved coding schemes for line-drawing data, especially topographic maps, and (3) the development of thoroughly tested computer programs for eliminating the

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20 Abstract

"hidden" lines in perspective views of complex planar-faced and quadric-surface-face objects. The individual research areas are briefly described and abstracts of the publications issued during the reporting period are given.

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